Williams, M.J., and C.G. Chambliss. 1999. Rhizoma perennial peanut. p. 49–52. *In* C.G. Chambliss (ed.) Florida Forage Handbook. Florida Coop. Ext. Serv. SP 253. Univ. of Florida, Gainesville.
Williams, M.J., C.A. Kelly-Begazo, R.L. Stanley Jr., K.H. Quesenberry, and G.M. Prine. 1997. Establishment of rhizoma peanut: Interaction of cultivar, planting date, and location on emergence and rate of cover. Agron. J. 89:981–987.
Wilson, J.R. 1983. Effects of water stress on in vitro dry matter digestibility and chemical composition of herbage of tropical pasture plants. Aust. J. Agric. Res. 34:377–390.

Herbage Accumulation of Three Bahiagrass Populations during the Cool Season

Roger N. Gates,* Paul Mislevy, and Frank G. Martin

ABSTRACT

Fall and winter are periods of critical forage shortage in subtropical regions of the world, including the extreme southeastern USA. Cool-season herbage accumulation has not been documented for bahiagrass [*Paspalum notatum* Flügge var. *saurae* Parodi] that has been selected using recurrent restricted phenotypic selection (RRPS) for increased warm-season yield. Regrowth of 'Pensacola', 'Tifton 9', and RRPS Cycle 18 that accumulated for 15 or 30 d was harvested from mid-September through mid-April at Tifton, GA and Ona, FL for 2 yr. Herbage accumulation was essentially parallel for the three populations; minimums were coincident in midwinter, and maxima generally occurred at the first autumn harvest or last spring harvest. Fall and spring yields of Tifton 9 and RRPS Cycle 18 were generally higher than those of Pensacola and often more than double. This advantage was more pronounced at Ona than Tifton. Digestibility (600 g kg^{-1}) and crude protein (CP) concentration (150 g kg^{-1}) at Ona remained high throughout the cool season. However, forage quality of bahiagrass at Tifton tended to decrease with increased frosts. Cool-season growth of three bahiagrass populations was slow, but RRPS selection has led to populations with greater growth potential, except when cold temperatures prohibit growth entirely.

Warm-season perennial grasses, particularly bermudagrass [*Cynodon dactylon* (L.) Pers.] and bahiagrass, provide the feed supply base for cow calf production in the lower South. These forages provide abundant feed of adequate nutritional value from late spring through early autumn. This predictable seasonal distribution of growth leads to equally predictable periods of feed shortage that are often most critical in late fall and early winter. Feed supplies must be supplemented with hay, concentrates, or cool-season annual forages when warm-season grasses are not actively growing. Mean daily temperatures during autumn, winter, and early spring range between about 9 and 26°C and are adequate to support the growth of cool-season species. Bermudagrass is dormant during winter, following freezing temperatures. Bahiagrass, in contrast, can remain green, especially at winter temperatures >0°C.

Although Pensacola bahiagrass was not introduced into North America until 1936 (Burton, 1967), its widespread proliferation throughout the lower southeastern USA demonstrates excellent adaptation by this species to regional environmental conditions. Bahiagrass is particularly tolerant of poor soil drainage, close continuous grazing, and marginal fertility.

Beginning in 1960, Burton (1974, 1982) used modified mass selection (RRPS) to develop improved bahiagrass populations from the diploid cultivar Pensacola. Tifton 9, resulting from nine cycles of RRPS, is higher yielding than Pensacola and was released in 1987 (Burton, 1989). Eighteen cycles of RRPS breeding resulted in the experimental population RRPS Cycle 18, which is higher yielding than both Pensacola and Tifton 9 (Burton et al., 1997). Increased spring herbage accumulation was the basis for the selection of Tifton 9 and RRPS Cycle 18 (Burton, 1974, 1982, 1989), and yield advantages during the typical growing season have been demonstrated (Pedreira and Brown, 1996; Burton et al., 1997; Gates et al., 1999). One possible approach to reduce the critical forage deficits occurring from fall through spring is to identify bahiagrass populations that are more productive under cool temperatures.

Previous research has demonstrated that bahiagrass makes 86% of its growth during the six warmest months of the year, even in peninsular Florida (Beaty et al., 1980; Mislevy and Everett, 1981). However, the duration of the period of active growth has not been thoroughly examined. Previous observations indicate the improved cultivar Tifton 9 accumulated 30% more forage during winter than Pensacola (Mislevy et al., 1990). It is not known if selection for increased yield has simply increased herbage accumulation at all temperatures, or if an increase occurred above some temperature threshold. An evaluation of the cool-season production of recently developed bahiagrass cultivars and populations with the potential for greater total herbage growth is a logical starting point to increase cool-season bahiagrass production.

Research was conducted to monitor the distribution of growth during the cool months (Oct.–Mar.) of the year for three diverse bahiagrass populations: Pensacola, Tifton 9, and RRPS Cycle 18. The objectives were to quantify the herbage accumulation and forage quality of aboveground biomass.

MATERIALS AND METHODS

This field study was conducted during the fall and winter of 1993–1994 and 1994–1995 at the Coastal Plain Experiment Station, Tifton, GA (31°26′ N, 83°35′ W) on Alapaha sand

R.N. Gates, USDA-ARS, Crop Genet. and Breeding Res. Unit, Coastal Plain Exp. Stn., Tifton, GA 31793; P. Mislevy, Univ. of Florida, Inst. of Food and Agric. Sci., Range Cattle Res. and Educ. Cent., Ona, FL 33865; and F.G. Martin, Inst. of Food and Agric. Sci., Dep. of Statistics, Univ. of Florida, Gainesville, FL 32611-0339. Received 3 Feb. 2000. *Corresponding author (rngates@tifton.cpes.peachnet.edu).

Published in Agron. J. 93:112–117 (2001).

Abbreviations: CP, crude protein; IVDMD, in vitro dry matter disappearance; IVOMD, in vitro organic matter disappearance; RRPS, recurrent restricted phenotypic selection.

Table 1. Stage, harvest, and midpoint date and duration of regrowth intervals for three bahiagrass entries grown at Tifton, GA and Ona, FL during the 1993–1994 and 1994–1995 seasons.

Ona				Tifton			
	Date				Date		
Stage	Harvest	Midpoint	Regrowth duration	Stage	Harvest	Midpoint	Regrowth duration
			days				days
15 Sept.	30 Sept.	23 Sept.	15	15 Sept.	30 Sept.	23 Sept.	15
30 Sept.	15 Oct.	08 Oct.	15	30 Sept.	15 Oct.	08 Oct.	15
15 Oct.	30 Oct.	23 Oct.	15	15 Oct.	30 Oct.	23 Oct.	15
30 Oct.	14 Nov.	08 Nov.	15	30 Oct.	14 Nov.	08 Nov.	15
				14 Nov.	29 Nov.	22 Nov.	15
14 Nov.	14 Dec.	29 Nov.	30				
				29 Nov.	29 Dec.	14 Dec.	30
14 Dec.	13 Jan.	29 Dec.	30				
				29 Dec.	28 Jan.	13 Jan.	30
13 Jan.	12 Feb.	28 Jan.	30	28 Jan.	12 Feb.	05 Feb.	15
12 Feb.	27 Feb.	20 Feb.	15	12 Feb.	27 Feb.	20 Feb.	15
27 Feb.	14 Mar.	07 Mar.	15	27 Feb.	14 Mar.	07 Mar.	15
14 Mar.	29 Mar.	22 Mar.	15	14 Mar.	29 Mar.	22 Mar.	15
29 Mar.	13 Apr.	06 Apr.	15	29 Mar.	13 Apr.	06 Apr.	15

(loamy, siliceous, thermic Arenic Plinthic Paleaqults) and at the University of Florida Range Cattle Research and Education Center, Ona, FL (27°26′ N, 81°55′ W) on Pomona fine sand (sandy, siliceous, hyperthermic Ultic Alaquod). Bottom plowing and discing were used for seedbed preparation, followed by seeding (11.2 kg ha^{-1}) with a cultipacker seeder[1]. Plots were seeded 12 May 1993 at Tifton and 22 June 1992 at Ona. One seed lot each of Pensacola, Tifton 9, and RRPS Cycle 18 was used at both locations. Bahiagrass entries were planted in strips (1.2 by 14 m) that were assigned at random as whole-plot factors in a randomized complete block arrangement with four replications at each location. Harvest dates (Table 1) as subplots (1.2 by 1.0 m) were assigned randomly within whole plots. Plots were fertilized (34 kg N ha^{-1}) at planting and at 6 (34–7–28 kg ha^{-1} N–P–K) and 10 wk (34 kg N ha^{-1}) after planting at Tifton. Establishment fertilization at Ona consisted of 56–15–56 kg ha^{-1} N–P–K 65 d after seeding. Plots at Ona were treated with bentazon (3-isopropyl-1 *H*-2, 1-3-benzothiodiazin-[4] 3 *H*-one 2,2-dioxide) at 0.85 kg ha^{-1} to control sedges. At Tifton, 56, 24, and 46 kg ha^{-1} N-P-K was applied each year in mid-August. Annual fertilization at Ona included an early September application of 15 kg P ha^{-1} and 56 kg K ha^{-1}. Plots that were scheduled to be harvested by mid-January received 56 kg N ha^{-1} in early September. Plots that were scheduled to be harvested after mid-January received 56 kg N ha^{-1} in mid-December. Periodic summer mowing was used to control weeds.

Each subplot was staged by cutting the entire subplot to a 50-mm stubble to remove previously accumulated growth. Regrowth was allowed for 15 or 30 d depending on the date, and yield was determined by cutting a 0.5-m^2 quadrat placed centrally in the plot to a 50-mm stubble. The regrowth interval was increased from 15 to 30 d during the coldest portion of the year and then decreased from 30 to 15 d again in spring (Table 1). Subplots were staged separately, once each growing season, rather than repeatedly harvesting plots, to avoid the potential depletion of reserve carbohydrates. Daily air and soil temperatures, precipitation, and solar radiation were recorded at a weather station 200 m from the plot area at Tifton and 600 m from the plot area at Ona.

Herbage harvested from each subplot was oven-dried (60°C), weighed, and ground (1-mm stainless steel screen) in preparation for laboratory analysis. Daily herbage accumulation was calculated as the ratio of dry matter harvested to the length of the regrowth interval and was associated with the chronological midpoint of the regrowth interval for presentation and analysis.

Samples collected at Ona were analyzed for total N (Gallaher et al., 1975; Hambleton, 1977) and in vitro organic matter disappearance (IVOMD; Moore and Mott, 1974). Crude protein content was calculated as 6.25 × N. Digestibility was estimated from Tifton samples using the same direct acidification procedures, but samples were not ashed and digestibility was expressed on a dry matter basis as in vitro dry matter disappearance (IVDMD), instead of on an organic matter basis.

Sampling schedules were slightly different at the two locations, and growth patterns were distinct, reflecting higher midwinter temperatures at Ona. Separate statistical analyses were conducted for each location. Interpretation was enhanced by a separate analysis for each year within a location because of interactions with harvest year. Analysis of variance for each variable used a model including the effects: harvest, bahiagrass entry, replication, and the interactions. When interactions between harvest and bahiagrass entries were detected, these interactions were investigated using Duncan's multiple range test (Steel and Torrie, 1960). The experiment was treated as a repeated-measures experiment with three bahiagrass entries (whole plots) arranged in four randomized complete blocks. Harvest date (subplot) was the repeated-measures factor. The repeated-measures experiment is a form of the split-plot experiment, but it differs in that the subplot treatment cannot be randomized; the first harvest must always precede the second, which must always precede the third, and so on. Although it is an approximate analysis, a valid analysis of data from repeated-measures experiments can be obtained from the standard split-plot analysis. No evidence was obtained that suggested that this was not the case for data from this experiment (Martin, unpublished data, 1996).

RESULTS AND DISCUSSION

Herbage Accumulation

Location and Date

Mean daily maximum and minimum temperatures, calculated for each 15- or 30-d growth interval, were 6°C cooler at Tifton than at Ona (Fig. 1). During the two seasons, temperatures fell below zero on only one night at Ona. Freezing temperatures were recorded on

[1] Brillion AG Model Sure Stand Grass Seeder SSPT60, Brillion Iron Works, Brillion, WI 54110.

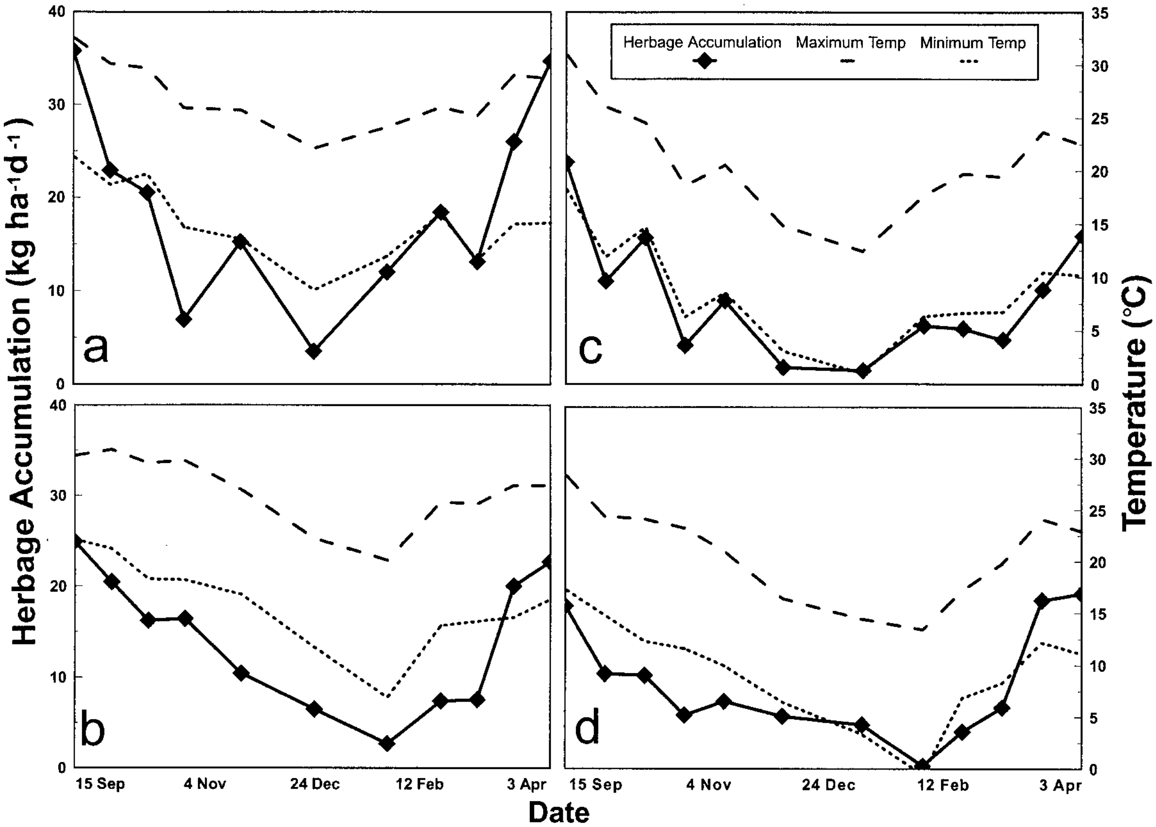

Fig. 1. Mean daily maximum and minimum temperatures and mean daily herbage accumulation of three bahiagrass entries during each growth period of 15 or 30 d during (*a*) 1993–1994 and (*b*) 1994–1995 at Ona, FL and (*c*) 1993–1994 and (*d*) 1994–1995 at Tifton, GA.

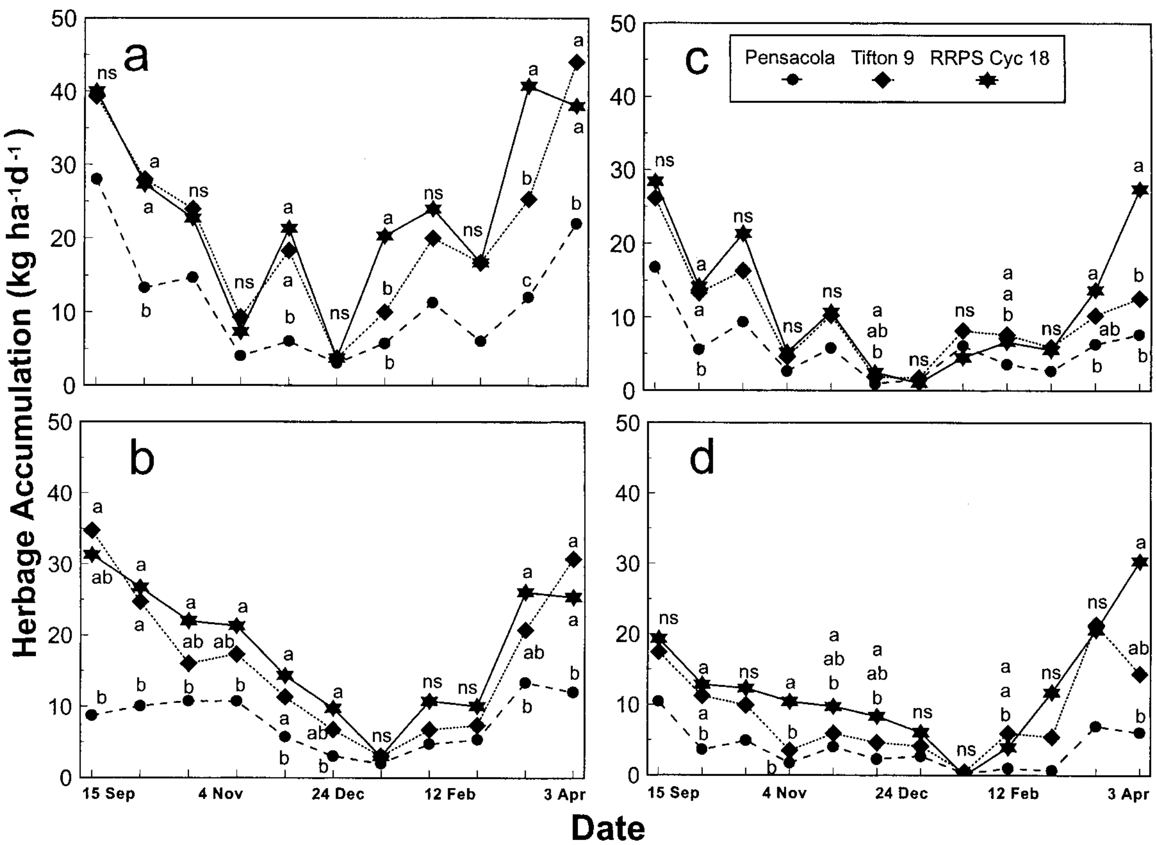

Fig. 2. Mean daily herbage accumulation of three bahiagrass entries during each growth period of 15 or 30 d during (*a*) 1993–1994 and (*b*) 1994–1995 at Ona, FL and (*c*) 1993–1994 and (*d*) 1994–1995 at Tifton, GA. Within sampling dates, means accompanied by different letters are significantly different ($P < 0.05$); ns, not significantly different.

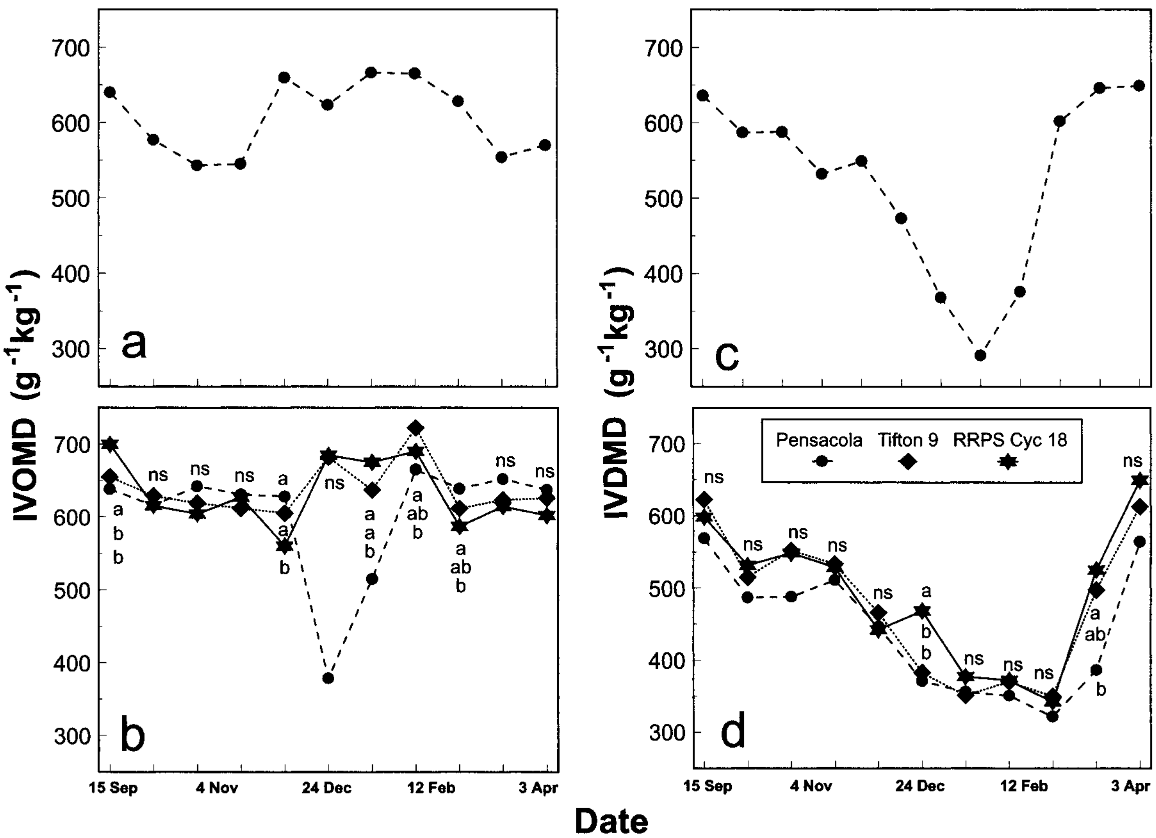

Fig. 3. Mean in vitro organic matter disappearance (IVOMD) of three bahiagrass entries during each growth period of 15 or 30 d during (*a*) 1993–1994 and (*b*) 1994–1995 at Ona, FL and mean in vitro dry matter disappearance (IVDMD) of each of three bahiagrass entries during (*c*) 1993–1994 and (*d*) 1994–1995 at Tifton, GA. Within sampling dates, means accompanied by different letters are significantly different ($P < 0.05$); ns, not significantly different.

29 d in 1993–1994 and on 18 d in 1994–1995 at Tifton. The chronological pattern of herbage accumulation was similar between years and locations, and it included a rapid decline in herbage accumulation in autumn. Mean herbage accumulation at Ona decreased from 36 to 23 kg ha^{-1} from 23 Sept. to 8 Oct. 1993 and from 20 to 7 kg ha^{-1} d^{-1} from 23 Oct. to 8 Nov. 1993. These data represent a decrease of 29 kg ha^{-1} d^{-1} within a 46-d period. Daily herbage accumulation ranged between 5 and 15 kg ha^{-1} d^{-1} from 8 November through 7 March, after which herbage accumulation accelerated from 13 to 35 kg ha^{-1} d^{-1} (7 Mar.–6 Apr.) for an increase of 169% within a 30-d period. During the 1994–1995 season at Ona, decrease in fall accumulation was similar to the previous year. However, during 1994–1995, herbage accumulation between 29 November and 7 March was less than 15 kg ha^{-1} d^{-1}, followed by a rapid 2.6-fold increase between 7 March and 6 April.

Herbage accumulation at Tifton followed a pattern similar to Ona, with the exception of a lower overall herbage accumulation. The rate of herbage accumulation decreased by 13 kg ha^{-1} d^{-1} from 23 Sept. to 8 Oct. 1993, followed by a 5 kg ha^{-1} d^{-1} increase from 8 to 23 October, which was followed again by a decrease of 11 kg ha^{-1} d^{-1} from 23 October to 8 November and then an increase of 5 kg ha^{-1} d^{-1} from 8 to 22 November. The lowest rate of herbage accumulation was 2 kg ha^{-1} d^{-1} between 14 December and 13 January. Herbage accumulation continued to be low, ranging from 3 to 5 kg ha^{-1} d^{-1} until 7 March, after which herbage accumulation increased rapidly.

Herbage accumulation during the fall of 1994–1995 at Tifton decreased from 23 September to 5 February, followed by a continuous increase until 6 April. Herbage accumulation from 8 October until 7 March was <10 kg ha^{-1} d^{-1}. The herbage accumulation curves at Tifton tended to be closely associated with the minimum temperature curve. Mean herbage accumulation was slower at Tifton (8.6 kg ha^{-1} d^{-1}) than at Ona (16.6 kg ha^{-1} d^{-1}).

Bahiagrass Entries

The herbage accumulation of RRPS Cycle 18 was generally greater numerically than the other entries, and Tifton 9 and RRPS Cycle 18 herbage tended to accumulate at higher rates than that of Pensacola (Fig. 2). Differences among bahiagrass entries ($P < 0.05$) were detected for 13 of 22 harvest dates at Ona and 11 of 24 dates at Tifton. For 20 of 22 dates at Ona and 22 of 24 dates at Tifton, the herbage accumulation of RRPS Cycle 18 and Tifton 9 was not different ($P > 0.05$). The herbage accumulation of RRPS Cycle 18 was greater ($P < 0.05$) than that of Pensacola in 13 of 22 harvest dates at Ona and 11 of 24 harvest dates at Tifton.

Average herbage accumulation across all harvests at Ona for Tifton 9 and RRPS Cycle18 (avg. of both entries) and Pensacola was 20.6 and 10.1 kg ha^{-1} d^{-1} for

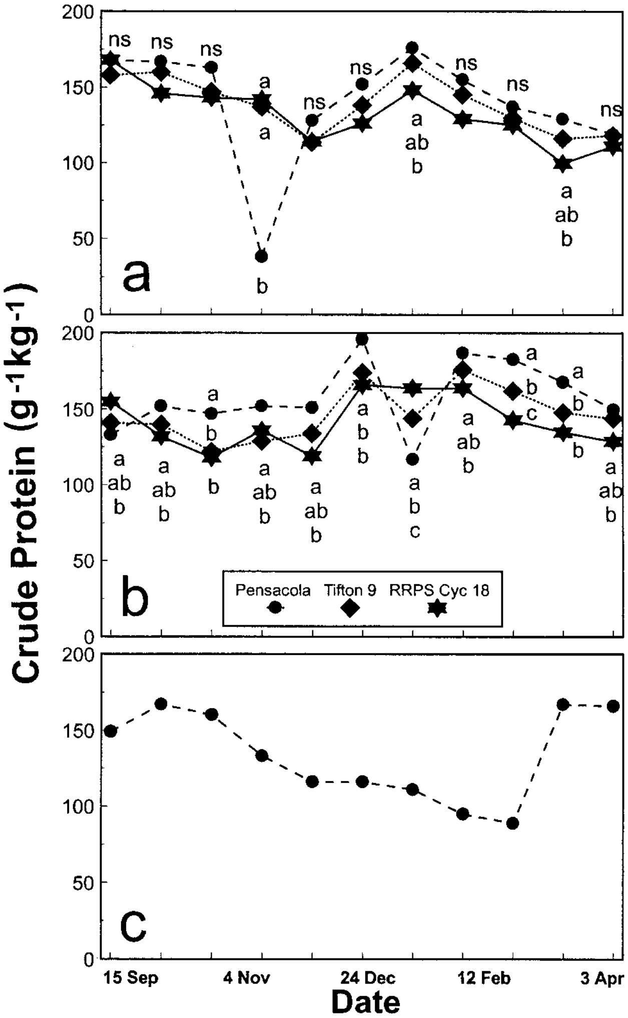

Fig. 4. Mean crude protein (CP) of each of three bahiagrass entries during each growth period of 15 or 30 d during (*a*) 1993–1994 and (*b*) 1994–1995 at Ona, FL and (*c*) 1994–1995 at Tifton, GA. Within sampling dates, means accompanied by different letters are significantly different ($P < 0.05$); ns, not significantly different.

1993–1994 and 15.3 and 6.9 kg ha^{-1} d^{-1} for 1994–1995, respectively. At Tifton, herbage accumulation for the same entries and Pensacola was 9.5 and 5.1 kg ha^{-1} d^{-1} for 1993–1994 and 9.7 and 3.5 kg ha^{-1} d^{-1} during the 1994–1995 cool season, respectively.

These data indicate that the average herbage accumulation of the two selected populations was 104% higher during 1993–1994 and 122% higher in 1994–1995 than Pensacola bahiagrass at Ona. At Tifton, average herbage accumulation for Tifton 9 and RRPS Cycle 18 was 86 and 177% higher than Pensacola during 1993–1994 and 1994–1995, respectively. Even though the average low temperature during the cool season was considerably lower at Tifton compared with Ona, Tifton 9 and RRPS Cycle 18 continued to produce higher dry matter yields than Pensacola bahiagrass at that location.

Digestibility

Location and Date

Digestibility estimates exceeded 500 g kg^{-1} on all occasions at Ona, except on 29 Dec. 1994, and were generally higher than 600 g kg^{-1} (Fig. 3a, 3b). At Tifton, by contrast, the digestibility estimates were high in autumn and early spring but fell to between 300 and 350 g kg^{-1} during winter (Fig. 3c, 3d). The absence of freezing temperatures preserved tissue integrity at Ona, maintaining a relatively high digestibility. At Tifton, frequent midwinter freezes caused severe tissue damage and death, substantially lowering the digestibility of the harvested herbage.

Bahiagrass Entries

During 1993–1994, differences in digestibility due to entry were not detected ($P > 0.05$) at either location (Fig. 3a, 3c). The digestibility of RRPS Cycle 18 was greater ($P < 0.05$) than that of Pensacola on two dates during 1994–1995 at Tifton (Fig. 3). Differences ($P < 0.05$) in digestibility attributable to bahiagrass entry were also detected on five dates during 1994–1995 at Ona (Fig. 3). However, no entry was consistently high or low compared with other entries. Previous studies by Mislevy et al. (1990) had also revealed little difference in IVOMD ($\leq$9 g kg^{-1}) between Tifton 9 and Pensacola bahiagrass at various grazing frequencies.

Crude Protein

Samples harvested from both seasons at Ona were analyzed for CP concentration. A sufficient sample for analysis was only available for 1994–1995 at Tifton.

Location and Date

With a single exception, CP concentrations exceeded 100 g kg^{-1} and frequently exceeded 150 g kg^{-1} at Ona (Fig. 4). The CP concentrations remained relatively constant from autumn through early spring, ranging from about 130 to 170 g kg^{-1}. There was no evidence of any trend for increasing or decreasing CP concentration in either year. The CP concentrations declined progressively during the 1994–1995 harvests at Tifton (Fig. 4) in a pattern that was strikingly consistent with declines in IVDMD (Fig. 3). Apparently, freezing temperatures affected both nutrient parameters similarly although CP remained above 100 g kg^{-1}—a level sufficient for the nutrient demands of mature livestock during midwinter.

Bahiagrass Entries

Although CP concentration was numerically highest for Pensacola samples on all but one sample in 1993–1994 at Ona, differences ($P < 0.05$) were detected on only three dates; CP was higher ($P < 0.05$) for Pensacola than for RRPS Cycle 18 on two of the three dates (Fig. 4). A sudden decrease in CP value was encountered with Pensacola samples once in 1993–1994 and once in 1994–1995, which could indicate some type of sampling or laboratory error. During 1994–1995, CP in Pensacola samples at Ona was higher ($P < 0.05$) than in RRPS Cycle 18 samples on eight dates and exceeded Tifton 9 ($P < 0.05$) on five harvest dates (Fig. 4). This was consistent with previous findings of Mislevy et al. (1990), who demonstrated that CP concentration was 0 to 12 g kg^{-1} higher in Pensacola than in Tifton 9 bahiagrass. No differences in CP due to bahiagrass entry were detected at Tifton during 1994–1995 (Fig. 4).

It is clearly evident that RRPS selection within a bahiagrass population has increased the potential for herbage dry matter accumulation above the cutting height (50 mm) used in these experiments during the cool months of the year as well as during summer (Burton, 1989; Gates et al., 1999). The growth of all three populations was dramatically reduced by the coldest temperatures, most clearly at Tifton. Because the two environmental variables cannot be separated, growth may also be responding to the change in daylength. Blount et al. (2001) have recently demonstrated a high sensitivity of bahiagrass to daylength. The growth of advanced cycles from RRPS selection was much less responsive than Pensacola to supplemental artificial lighting during short days. The digestibility and CP of new accumulation of bahiagrass growth during winter remained high at Ona. At Tifton, fall and spring values were high, but the nutritive value in winter was depressed, apparently by freezing temperatures.

REFERENCES

Beaty, E.R., K.H. Tan, R.A. McCreery, and J.D. Powell. 1980. Yield and N content of closely clipped bahiagrass as affected by N treatments. Agron. J. 72:56–60.

Blount, A.R., T.R. Sinclair, R.N. Gates, K.H. Quesenberry, and R.C. Littell. 2001. Photoperiod response in ‘Pensacola’ bahiagrass. Proc. Int. Grasslands Congr., 29th, Piacicaba, Sao Paulo, Brazil. 10–21 Feb. 2000 (in press).

Burton, G.W. 1967. A search for the origin of Pensacola bahiagrass. Econ. Bot. 21:379–382.

Burton, G.W. 1974. Recurrent restricted phenotypic selection increases forage yields of Pensacola bahiagrass. Crop Sci. 14:831–835.

Burton, G.W. 1982. Improved recurrent restricted phenotypic selection increases bahiagrass forage yields. Crop Sci. 22:1058–1061.

Burton, G.W. 1989. Registration of ‘Tifton 9’ Pensacola bahiagrass. Crop Sci. 29:1326.

Burton, G.W., R.N. Gates, and G.J. Gascho. 1997. Response of Pensacola bahiagrass to rates of nitrogen, phosphorus, and potassium fertilizers. Soil Crop Sci. Soc. Fla. Proc. 56:31–35.

Gallaher, R.N., O.C. Weldon, and J.G. Futral. 1975. An aluminum block digester for plant and soil analyses. Soil Sci. Soc. Am. Proc. 39:803–806.

Gates, R.N., G.M. Hill, and G.W. Burton. 1999. Response of selected and unselected bahiagrass populations to defoliation. Agron. J. 91:787–795.

Hambleton, L.G. 1977. Semiautomated method for simultaneous determination of phosphorus, calcium, and crude protein in animal feeds. J. Assoc. Off. Anal. Chem. 60:845–854.

Mislevy, P., G.W. Burton, and P. Busey. 1990. Bahiagrass response to grazing frequency. Soil Crop Sci. Soc. Fla. Proc. 50:58–64.

Mislevy, P., and P.H. Everett. 1981. Subtropical grass species response to different irrigation and harvest regimes. Agron. J. 73:601–604.

Moore, J.E., and G.O. Mott. 1974. Recovery of residual organic matter from in vitro digestion of forages. J. Dairy Sci. 57:1258.

Pedreira, C.G.S., and R.H. Brown. 1996. Yield of selected and unselected bahiagrass populations at two cutting heights. Crop Sci. 36:134–137.

Steel, R.G.D., and J.H. Torrie. 1960. Principals and procedures of statistics, with special reference to biological sciences. 1st ed. McGraw-Hill, New York.